The BIX Family – A Summary of Recent Technology Advancements

Burhanettin Koc, Sebastian Kist, Simon Kapelke

Physik Instrumente (PI) SE & Co. KG, Karlsruhe, Germany

b.koc@pi.de

Abstract
In an inertia-type motor, a piezoelectric multilayer actuator is exposed to a transient vibration velocity of more than 1.0 m/s during slip time, which is in the range of a few microseconds (1 to 3 µs). In the bi-phase inertia drive (BIX) stator structures, slow (stick) and fast (slip) movements are shared by at least two piezoelectric multilayer actuators. In the BIX family, an even number of PICMA® multilayer actuators are arranged in various configurations to form a stator. These stators are integrated into linear, rotary, and spindle drive structures designed for nanopositioning systems. While the one-sided BIX, two-sided BIX, and BIX spindle drive structures provide motion with a single degree of freedom, the 2D-BIX stator can provide motion in two directions. In this study these stator structures are presented.

BIX, PICMA® Multilayer Actuators, Piezoelectric Inertia Drive, Nanopositioning Stage

1. Introduction

In an inertia drive type (stick-slip) piezoelectric motor, a friction coupler at the interface between a slider and a stator makes a tangential back-and-forth movement. In one direction of the tangential movement, the friction coupler of the stator element is activated slowly within one period of a sawtooth drive signal. During this time, the moving part (a slider or a rotor) moves together with the friction coupler of the stator element. In the opposite direction of the tangential movement, the corresponding force acting on the friction coupler is greater than the friction holding force, such that the moving part slips and maintains its position compared to the friction coupler on the stator. At the end of one sawtooth drive signal period, the moving part makes a microscopic step. Accumulation of these microscopic steps creates macroscopic movements. To obtain a step in opposite direction, the friction coupler on the stator element is activated fast, which makes the moving part slip and maintain its position. During the slow phase, the moving part moves relative to its initial position together with the friction coupler on the stator element [1].

In conventional inertia drive piezoelectric motors, steps in back-and-forth directions are not equal and the hysteretic nature of piezoelectric actuators introduces additional nonlinearity to the positioning systems. In the case of bi-phase inertia drive (BIX) structures, two piezoelectric multilayer actuators (PICMA®), framed by a base mass, are coupled by a friction coupler, and their deformations are synchronized by appropriate excitation of the actuators [2]. The sliding or moving element is in contact with the friction coupler (Fig. 1).

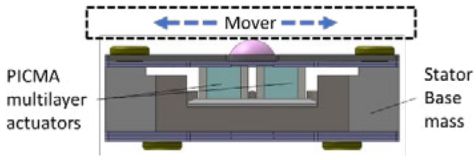

Figure 1. Appearance of a BIX stator in contact with a slider

The PICMA® multilayer actuators are driven by two sawtooth signals, which are anticyclic (mirrored) to each other. As one actuator expands, the other shrinks (Fig. 2). As a result, the combined movement of the multilayer actuators transferred to the friction coupler reduces hysteresis [3] and acceleration acting on the friction coupler is doubled at the slider contact point as both actuators contribute to the movements.

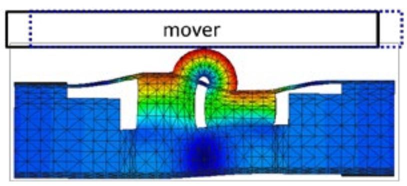

Figure 2. FEM analysis showing the BIX working principle

2. One-sided BIX ("Standard BIX")

The stator of the one-sided BIX consists of two PICMA® multilayer actuators, sandwiched between two insulation layers, which are placed adjacently in a U-shaped base mass (Fig. 3). The top of the actuators is covered with sheet metal layers, which apply a preloading force to the multilayer actuators in the direction of their length. A pair of flat springs made of sheet metal layers are used to hold the stator and apply a pressing force against the slider. As mentioned previously, driving the multilayer actuators with truncated sawtooth voltage signals of an anticyclic nature enhances the system dynamics.

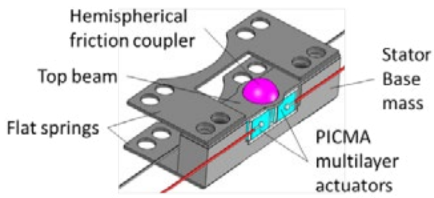

Figure 3. One-sided BIX stator

When integrating the one-sided BIX structure, pressing force can be applied in two ways. One is using flat springs, which hold the stators and apply pressing force against a moving element. The other is mounting the stator on a stage base plate, and a pressing force is applied behind a moving element such as a rotor or a slider.

3. Two-sided BIX ("Performance BIX")

In the two-sided BIX stator structure, two multilayer actuators are paired with two insulation layers, on which two friction couplers are attached at the geometric center of both end surfaces (Fig. 4). The PICMA® multilayer actuator pair with the insulation layers and the friction couplers are further framed by two identical L-shaped elastic elements, where paired PICMA® multilayer actuators in the stator are coupled to side masses symmetrically.

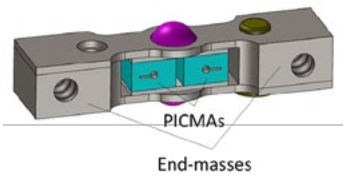

Figure 4. Two-sided BIX stator

Their simultaneous expansion and shrinkage, shown in Fig. 5, are transferred to the friction couplers. When a stator is mounted on a motor base, useful microscopic movements on the friction couplers are not affected from the fixation of the stator body. In this symmetrical structure, the multilayer actuators are allowed to expand and shrink simultaneously from both ends. The end masses (or base plates) located at both sides of the actuator pair, which are part of the elastic frame, stay silent. The darker blue color of the side masses indicates that these masses do not move while the PICMA® multilayer actuators deform; the red color, conversely, shows that the friction couplers move with the highest amplitude.

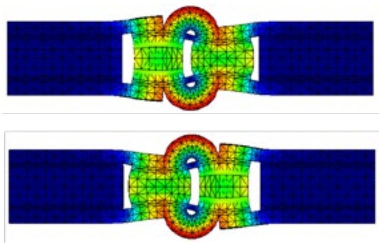

Figure 5. FEM analysis of the two-sided BIX stator during operation

Additionally, the structure is configured such that both friction couplers are in frictional contacts to the moving element (Fig. 6). This two-sided BIX structure doubles the generative force compared to the stages with the one-sided BIX stators. This force enhancement, on the other hand, sacrifices the velocity to be halved, since the deformations of the PICMA® multilayer actuators are distributed to both friction couplers.

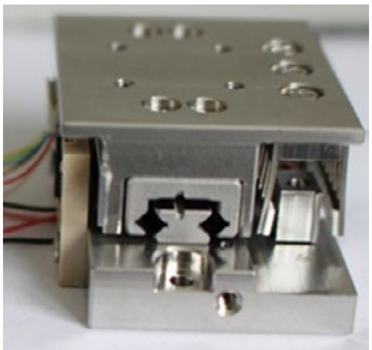

Figure 6. The use of two-sided BIX stator in a linear stage

However, the achievable velocity can be customized for specific applications, e.g., in cryogenic environments. Since actuator displacement at cryogenic temperatures decreases significantly, the structure of the stator can be optimized by using a longer PICMA® multilayer actuator pair according to performance specifications at cryogenic environment.

In the rotary motor structure shown in Fig. 7, two two-sided BIX stators are integrated. In this structure, the stators are mounted on the motor base plate and pressing force is generated by flat springs at the rotor side.

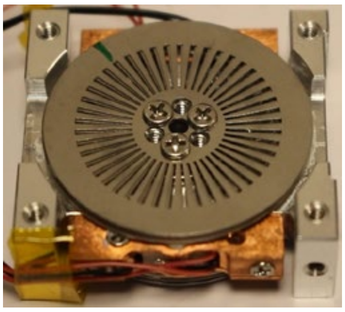

Figure 7. Rotary motor with two two-sided BIX stators

4. BIX spindle drive

In the BIX spindle drive structure, two PICMA® multilayer actuators are arranged in a framed structure such that friction couplers are in contact to a screw spindle from its two sides (Fig. 8).

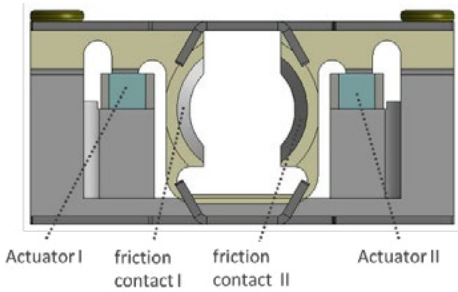

Figure 8. BIX spindle drive stator

As one actuator expands and the other shrinks, extended arms generate linear back and forth movements which are tangential to the screw spindle (Fig. 9). Since the arms are holding the spindle with a pressing force, these back-and-forth movements are transferred as rotational microscopic steps to the spindle. As the spindle has threads, rotational steps are converted to a linear movement perpendicular to the orientation plane of the structure.

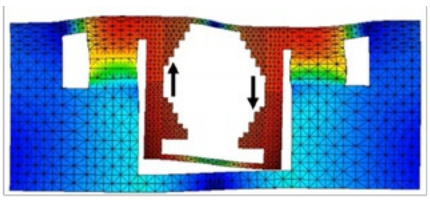

Figure 9. FEM analysis of the BIX spindle drive stator during operation

In a BIX spindle drive structure, two stators are integrated on a base plate as shown in Fig. 10, where an M6.5 screw with 0.5 mm pitch is used as the spindle. Such integration of two stator bodies eliminates passive guide used in conventional piezoelectric spindle drive structures and reduces friction losses within the system, thereby increasing the force that this drive mechanism can generate.

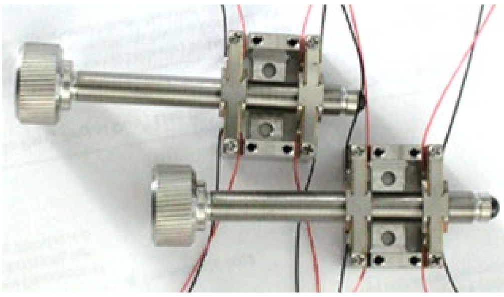

Figure 10. Functional model of the BIX-spindle drive

The BIX spindle drive structures have been integrated into a Z-tip-tilt stage for mirror alignment and a flexure guided linear stage for cryogenic environments as shown in Fig. 11.

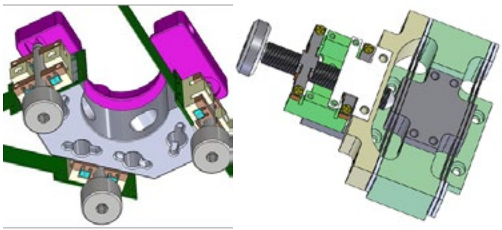

Figure 11. BIX spindle drives in a Z-tip/tilt mirror alignment unit and a flexure guided linear stage for cryogenic environment

Advanced driving of BIX spindle drive

In an inertia drive motor, there are two response times; one is the movement of multilayer actuators with the friction couplers, which is in the range of 1 to several microseconds, the other is the movement of the slider or rotor, in the case of the BIX spindle drive the screw spindle, which is several tens of microseconds. Both friction couplers are frictionally in contact to the screw spindle and it is known that the spindle movement takes place during slow stick time. However, without a slippage of the screw spindle, a net movement is not possible. Force generated by the PICMA® multilayer actuators during slip time is transferred to the friction coupler so that friction coupler can overcome the holding force and leave the spindle at its position.

In the BIX spindle drive, dependency of screw spindle inertia can be minimized by driving the structure with synchronous stick and asynchronous slip phase (Fig. 12). Such drive option is also friendly to drive electronics, since the two PICMA® multilayer actuators draw the high switching current at different times. A drive electronic with lower switching current requirements can be used for driving such a stage.

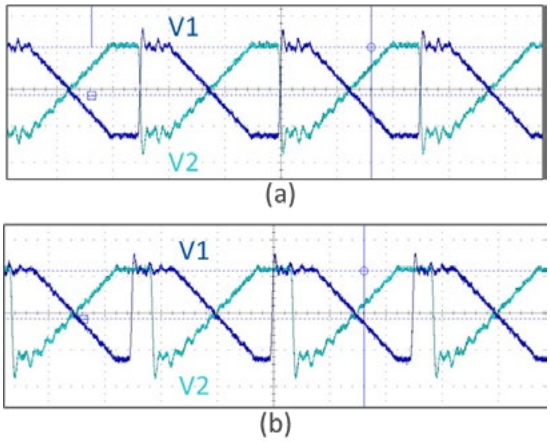

Figure 12. (a) Stick and slip phases are synchronous, (b) stick phase is synchronous and slip phase is asynchronous

Both synchronous stick and slip phases and synchronous stick and asynchronous slip phases have been demonstrated and both drive conditions can operate the BIX spindle drive stages.

5. 2D-BIX

Unlike previously summarized BIX family members, in which two PICMA® multilayer actuators are integrated in stator structures, here in 2D-BIX structure, four PICMA® multilayer actuators are arranged around a lever beam (Fig. 13). The same two sawtooth signals mirrored to one another are used to drive paired PICMA® multilayer actuators to obtain movement in two directions. The synchronous deformation of the actuators is amplified by the lever beam and transferred to a mirror unit. Such units can be operated both in analogue and step modes. As previously noted, step mode is driven by two sawtooth signals that are anticyclic (mirrored) to each other. In analog operating mode, however, the actuator pairs are driven by two triangular waveforms with a phase difference of 180 degrees relative to one another.

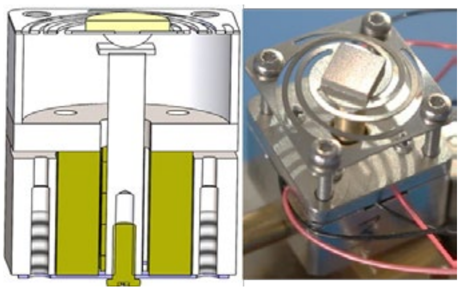

Figure 13. The use of 2D-BIX stator in a mirror tip/tilt stage

6. Summary

In an inertia-type piezoelectric motor, a multilayer actuator can expose to a transient vibration velocity—reaching up to 1.0 m/s—within a very short time, such as a few microseconds (1 to 3 µs). During this short interval, a multilayer actuator with a capacitance of 100 nF can draw a current pulse of up to 10 A; consequently, a transient accumulation of acceleration—and thus forces—is generated on the friction coupler. For relative slippage to occur between the friction coupler and the moving part (slider), this transient force acting on the friction coupler must exceed the holding force. The source of this energy is the transient current drawn by the multilayer actuator.

In the case of BIX stators, both multilayer actuators contribute to the generation of the transient force accumulated on the friction coupler. Compared to motor architectures utilizing a single actuator, dual-actuator motor architectures—such as the BIX—exhibit a higher traction force.

The described driving principle has been demonstrated using various stator structures, namely the one-sided and two-sided BIX stators as well as the BIX spindle drive and 2D-BIX structures. Corresponding linear, rotary and tip/tilt stages are available as prototypes or functional models.

References

[1] Higuchi T and Watanabe M 1987 U.S. Patent 4 894 579

[2] Koc B and Delibas B 2023 Actuators **12** 52

[3] Satoru T 1991 Japanese Patent 1991283580A